Effects of soil temperature and soil water content on soil respiration in three forest types in Changbai Mountain

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Abstract: Soil incubation experiments were conducted in lab to delineate the effect of soil temperature and soil water content on soil respirations in broad-leaved/Korean pine forest (mountain dark brown forest soil), dark coniferous forest (mountain brown coniferous forest soil) and erman's birch forest (mountain soddy forest soil) in Changbai Mountain in September 2001. The soil water content was adjusted to five different levels (9%, 21%, 30%, 37% and 43%) by adding certain amount of water into the soil cylinders, and the soil sample was incubated at 0, 5, 15, 25 and 35 °C for 24 h The results indicated that in broad-leaved/Korean pine forest the soil respiration rate was positively correlated to soil temperature from 0 to 35 °C. Soil respiration rate increased with increase of soil water content within the limits of 21% to 37%, while it decreased with soil water content when water content was over the range. The result suggested the interactive effects of temperature and water content on soil respiration. There were significant differences in soil respiration among the various forest types. The soil respiration rate was highest in broad-leaved/Korean pine forest, middle in erman's birch forest and the lowest in dark coniferous forest. The optimal soil temperature and soil water content for soil respiration was 35°C and 37% in broad-leaved/Korean pine forest, 25 °C and 21% in dark coniferous forest, and 35 °C and 37% in erman's birch forest. Because the forests of broad-leaved/Korean pine, dark coniferous and erman's birch are distributed at different altitudes, the soil temperature had 4-5 °C variation in different forest types during the same period. Thus, the soil respiration rates measured in brown pine mountain soil were lower than those in dark brown forest and those measured in mountain grass forest soil were higher than those in brown pine mountain soil.
Key words: Soil temperature; Soil water content; Soil respiration; The typical forest ecosystem in Changbai Mountain.
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Introduction

Carbon element is a key component for organisms on the earth surface and it is one of the most active elements in terrestrial biogeochemical processes. Moreover, carbon serves as an important marker for well-developed biosphere (Gupta and Singh 1981). Since industrial revolution the process of carbon cycling has changed dramatically, which is mainly due to human activity such as fossil fuel combustion and land-use change. These lead to the global ecological and environmental changes including an increase of atmospheric CO_2 and climate warming etc.. The composition, structure, and function of the terrestrial ecosystem are greatly influenced, and this is a great challenge for the survival and sustaining development of human being. Soil is a large carbon sink. It is possible that slight change of soil respiration will induce a significantly difference in atmospheric CO_2 (Li *et al.* 1981; Moore and Dalva 1993; Moore and Knowle 1989). Therefore, there are many environmental factors affecting the release of CO_2. The most important ones are soil temperature and soil water content. Although there are some reports about this aspect, the mechanism of effects of soil temperature and soil water content on soil respiration is still unclear. There is no report in the soil respiration in forest ecosystem of Changbai Mountain. In this study, soil respiration rate was separately measured by the experimental method in broad-leaved/Korean pine forest, dark coniferous forest and erman's birch forest. CO_2 emission rate in soil carbon sink was estimated under different soil water contents and soil temperatures. The results might provide the data for the studies of carbon cycling on forest ecosystem and the response of global change.

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Study area and methods

Experimental site

The study site is located at the northern slope of Natural Reserve Zone of Changbai Mountain. The vegetative cover presents the vertical distribution, with the order of from top to bottom: alpine tundra, erman's birch forest, dark coniferous forest, and broad-leaved/Korean pine forest. This site is a typically natural comprehensive body in northeast of Eurasian continent. The soil is sampled from 3 zonal vege-

vegetations.

The broad-leaved/Korean pine forest is distributed at altitudes of 500-1 000 m. Average annual temperature ranges from 0.9 °C to 3.9 °C. Average annual precipitation is about 700 mm. The dominant tree species are classified as *Pinus koraiensis, Acer mono, Tilia amurensis, Ulmus mongolica, Fraxinus mandshurica* and *Quercus mongolica*. The mean diameter at breast height (DBH) of *Pinus koraiensis* is 28.9 cm and its average age is 160. Shrub includes *Deutzia amurensis, Acer pseudo - sieboldiarum, A. tegmentosum,* and *Corylus mandshurica* etc.. The herb is classified as *Carex spp, Brachybotrys paridiformis,* and some mosses. The soil is the mountain dark brown forest soil.

Dark coniferous forest is distributed at high latitude of 1 100-1 700 m in northern slope of Chnagbai Mountain. Here average annual temperature is in range of -2.3-0.9 °C. Average annual precipitation is about 800 mm. The dominant tree species in the forest are *Picea koraiensis, P. koyamai* var. *koraiensis, Abies nephrolepis* and *Pinus koraiensis*. The mean diameter at breast height of *Picea koraiensis* is 29 cm and its average age is 160. Moreover, there are some *Larix olgensis* and few broad-leaved tree species. The soil is mountain brown coniferous forest soil.

Erman's birch forest is distributed at the latitudes of 1 700-2 000 m, on the top of Changbai Mountain. Here average annual temperature ranges from -3.2 °C to -2.3 °C. Average annual precipitation is in range of 1 000 -1 400 mm, with 600-900 mm from June to September. The soil is mountain soddy forest soil. The dominant tree species are *Betula ermanii, Larix olgensis* var. *changbaishanensis, Picea jezoensis* var. *komarovii,* and *Abies nephrolepis*. The mean diameter at breast height of *Betula ermanii* is 17-23.2 cm and its average age is 130. Shrub includes *Rhododendron chrysanthum, Sorbus pohuashanensis, Juniperus sibirica, Vaccinium vitis–idaea.*

The Physicochemical properties of soils above three sites were shown in Table 1.

Table 1. Physicochemical properties of soil at the three stands

Soil type	Below ground biomass[a] /kg·hm^{-2}	Organic matter[b] /%	Number of microorganisms[c] /10 000·g^{-1}	Total C [d] /%	Q_{10}
Broad-leaved/Korean pine forest	53 040.0	275.6	2 265.87	159.9	3.05
Dark coniferous forest	42 200.0	123.6	380.37	71.7	2.72
Erman's birch forest	36 310.0	221.3	1 719.80	128.3	3.67

Note: a--- data refers to the reference (Li *et al* 1981); b--- Cheng *et al.* 1981); c---(Xu and Zheng 1980); d---(Xu and Ding 1980)

Methods

Sampling and treatments

Soil incubation experiments were conducted to delineate the effect of soil temperature and soil water content on soil respiration. In September 2001, a steel collar (with the diameter of 18 cm) was inserted into the ground to a depth of approximately 20 cm (not including humus layer) at every sampling location in the three sites in Changbai Mountain. Total 10 soil cylinders were collected at each sampling location and 3 soil samples were randomly selected to measure the soil respiration. The other samples were kept in the plastic pots and put into the culture cabinet where the temperature was controlled for orthogonal test of soil water and temperature. The soil water content was adjusted to five different levels (9%, 21%, 30%, 37% and 43%) by adding certain amount of water into the soil cylinders. The soil sample was incubated at 0 °C, 5 °C, 15 °C, 25 °C and 35 °C for 24 h. Each treatment of temperature and water content was measured in triplicate. The top and the bottom of the pots were sealed completely to avoid water loss.

Measurement of soil respiration rate

The CO_2 release of soil was measured by using CI301PS portable CO_2 analyzer (CID Corporation, England). Respiration rate was measured in an open-top chamber designed by ourselves. When the concentration of CO_2 in the chamber kept balance the data were recorded. Determination of soil respiration for each treatment was calculated by using the following equation (Chen *et al.* 1999).

$$R = \frac{60 \times \mathrm{d}C \times V}{A \times \mathrm{d}t \times 100} \times \frac{44}{22.4} \times \frac{273}{273 + T} \times \frac{P}{760} \quad (1)$$

where dC is the difference of concentrations of CO_2 in chamber between pre- and post-CO_2 exchange (μl·L^{-1}); V is the gas flux (L·min^{-1}); A was area of the bottom surface in chamber (cm^2); 44 is molar weight (g); 22.4 is gas volume of 1 molar molecule under standard condition (L); P is gas pressure in measuring time (MPa); T is the temperature in measuring time (°C); R is soil respiration rate (mg CO_2·m^{-2}·h^{-1}).

Q_{10} of different forest soil

Values of Q_{10} (the relative increase of respiration rate for a temperature rise of 10 °C) were determined by measuring average respiration rates and soil temperatures of each temperature treatment group. We fit the relationship between soil respiration and soil temperature with a nonlinear curve (using least-square techniques) (Davidson *et al.* 1998):

$$R = \beta_0 e^{\beta_1 T} \quad (2)$$

$$Q_{10}=e^{10\beta_1} \qquad (3)$$

where R is soil respiration, T is soil temperature, and β_0 and β_1 are constants. This exponential relationship is commonly used to represent respiration rate as a function of temperature (Lavigne 1987).

Data Analysis

Data were analyzed by the SigmaStat 2.03 procedure of SAS (SAS, 1995). One-way ANOVA was used to test the differences.

Results and analysis

Broad-leaved/Korean pine forest

The soil respiration rates in different forest types in Changbai Mountain varied with the change of soil temperatures (Fig. 1). As shown in Fig. 1a, the soil respiration rate in broadleaved/Korean pine forest tended to increase with the increase of soil temperature under different soil water contents, and it dramatically increased when soil temperatures exceeded 15°C. That might be due to the fact that soil microorganisms and abiological oxidization are active when the soil temperature is 15-25 °C (Liu and Fang 1997). In addition, the soil respiration rates increased rapidly under soil water contents of 30%, 37% and 43%, but slowly under soil water contents of 9% and 21%. In each temperature treatment group, there was optimal water content for soil respiration rate. In broad-leaved/Korean pine forest the maximum soil respiration rate (2 569±267.45 mg $CO_2\cdot m^{-2}\cdot h^{-1}$) occurred under soil water content of 37%, which supported the results in prairie by Kucera (1971). When the soil water content reached 25%-30% the soil respiration began to increase. This indicated that the soil respiration rate in broad-leaved/Korean pine forest was affected not only by soil temperature, but also by soil water content. When the soil water content was less than 20%, the soil respiration basically stopped (Liu and Fang 1997; Behera and Pati 1986; Fang and Wei 1998; Xu *et al.* 1980; Yang 1989).

In broad-leaved/Korean pine forest, the soil respiration rate was a single peak curve under different soil water contents (Fig. 2a). The soil respiration rate rapidly increased with the increase of soil water content under optimal temperature, and then followed a linear decrease. Under soil water content of 37%, the maximum value of soil respiration rate was 2 569±267.45, 227.83±231.00, 962.78±67.00, 362.72±35.45 and 17.79±6.17 mg $CO_2\cdot m^{-2}\cdot h^{-1}$ at 35 °C, 25 °C, 15 °C, 5 °C, and 0 °C, respectively. It indicated that the soil respiration rate decreased with decrease of soil temperature. There was no significant difference in soil respiration rate among different soil water contents at 5 °C and 0 °C. Only when the temperature was over 15 °C, the soil respiration rates at different soil temperatures were significantly different and it is also significantly different under different soil water contents at the same temperature (P<0.01).

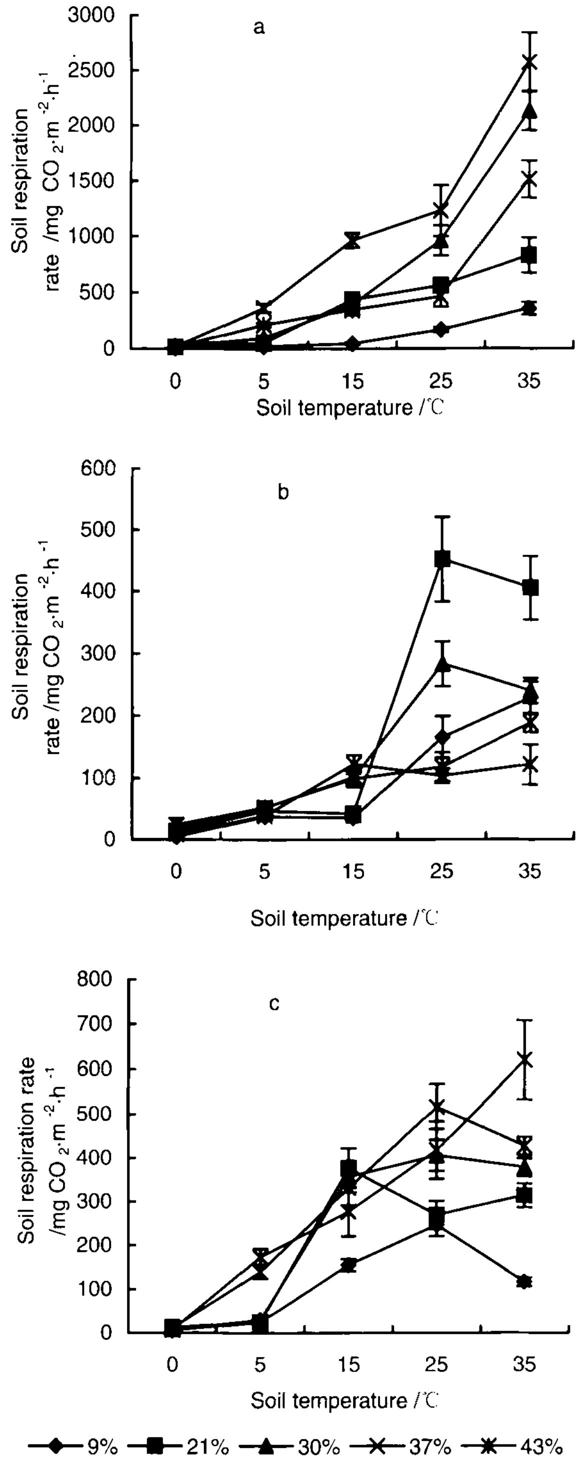

Fig. 1 Effect of soil temperature on soil respiration rate in different forest types.

a) Broad-leaved/Korean pine forest,

b) Dark coniferous forest,

c) Erman's birch forest.

Dark coniferous forest

The response of soil respiration rate in dark coniferous forest was not sensitive to the temperature ranged from 0 to 5 °C (Fig. 1b). Soil respiration rate tended to increase as soil temperature increased at low levels of soil water contents (9%, 21%, and 30%). but did not have significant change at high levels of soil water content (37% and 43%). The temperature breakpoint for soil respiration rate under different soil water contents was around 15 °C. From 15 °C to 35 °C, the soil respiration rate was highest at soil water content of 21% and lowest at soil water content of 43%. The result that the lowest soil respiration rate occurred at the highest soil water content was consistent with the study by Moore (Rainch and Schlesinger 1992). In dark coniferous forest, the maximum water capacity of soil was 37%, thus with the increase of soil water content, the porosity and air permeability of soil decreased. The activities of microorganisms in soil were affected by high soil water content, as a result, the soil respiration was inhibited. The results showed that the respiration rate of soil with different water content had no significant difference at temperatures of 0-15 °C.

The soil respiration rates at soil temperatures of 25 °C and 35 °C presented a high level (Fig. 2b) under soil water content of 21%, followed by a decrease when soil water content is over 21%. At low temperature (0-5°C), the soil respiration rate did not varied with the change of soil water content. When the temperature reached 15 °C the soil respiration rate tended to increase with soil water increasing. The mean soil respiration rates at 35, 25, 15, 5 and 0°C were 236.57±29.07, 224.56±36.41, 79.97±10.08, 45.70±7.67 and 14.53±5.69 $mg \cdot CO_2 \cdot m^{-2} \cdot h^{-1}$, respectively. There was no significant difference in soil respiration rate between soil temperatures of 35 °C and 25°C (P>0.05) in dark coniferous forest. The soil respiration in dark coniferous forest was lower than that in broad-leaved/Korean pine forest at soil temperatures in range of 5 °C to 35 °C.

Erman's birch forest

The soil respiration rate in Erman's birch forest tended to increase with the increase of the soil temperature at 0-15°C among different soil water treatments (Fig. 1c). When soil respiration rate increased to a certain level, it began to decrease. The breakpoint of soil temperature for oil respiration rate was between 15 °C and 25 °C. The soil respiration rate in Erman's birch forest was lower than those in broad-leaved/Korean pine forest and dark coniferous forest, because the microorganisms in the soil of erman's birch forest were adapted to the condition of low temperature. The soil respiration rate showed significant difference btween elevated temperature (15-35°C) and low temperature (0-5 °C) (P<0.01) by t test, while it had no significant difference at the elevated temperatures (P>0.05). The soil respiration rate at low temperature was lower than those at elevated temperatures. The mean soil respiration rate at 35°C was 41.1, 40.7, 33.3 and 8.7 times higher than those at 0, 5, 15 and 25 °C, respectively.

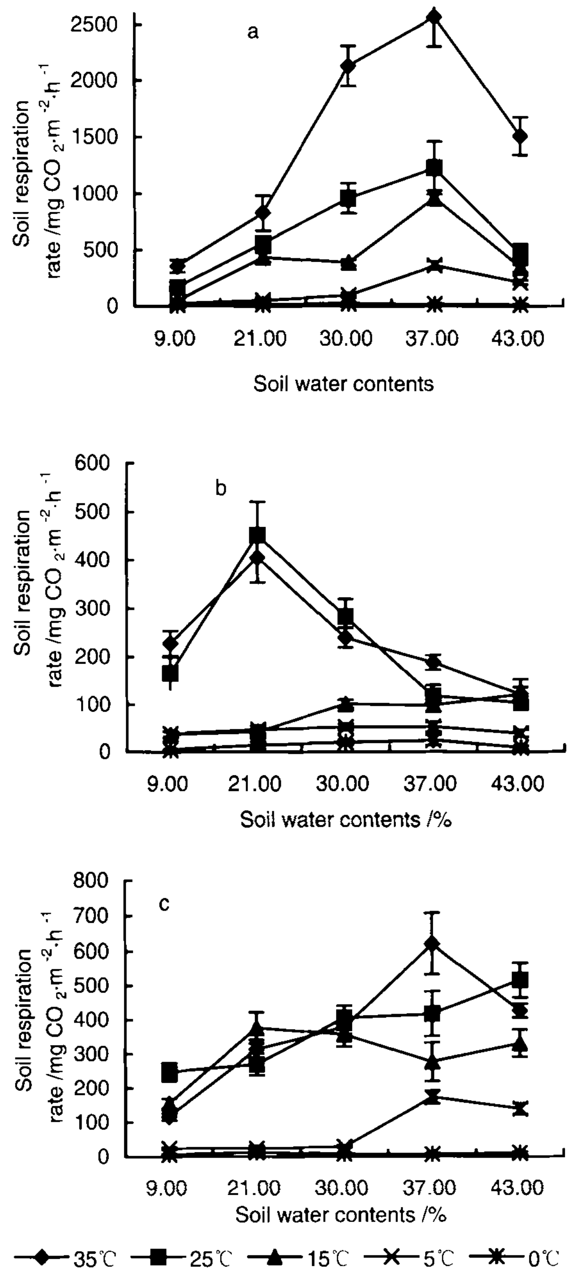

Fig. 2 Effects of water content on soil respiration rate in different forest types

a) Broad-leaved/Korean pine forest, b) Dark coniferous forest, c) Erman`s birch forest.

Under different soil water treatments the change of soil respiration rate at different soil temperatures was different in erman's birch forest from those in dark coniferous forest and broad-leaved/Korean pine forest. The soil respiration rates both at soil temperature of 5 °C and 35 °C peaked at soil water content of 37%. It is the reason that erman's birch forest in Changbai Mountain is distributed at high altitude

and rainfall is sufficient. The soil temperature was the main factor affecting the soil respiration but water was not. The mountain soddy forest soil of erman's birch forest is sandy and the air permeability was better than those of the soils in dark coniferous forest and broad-leaved/Korean pine forest (Cheng *et al.* 1981). And the amount of the microorganisms was less than that in dark coniferous forest and broad-leaved/Korean pine forest. The mean soil respiration rate was 12.78 mg $CO_2 \cdot m^{-2} \cdot h^{-1}$ at 0°C. Soil respiration rate remarkably increased when soil temperature exceeded 5°C, soil water content was 30% (Fig. 2c). The soil respiration rate was not significantly different at different soil temperatures when the temperature reached 15 °C.

Discussion

Carbon cycling is one of the most important processes in forest ecosystem and it is closely related to the energy flux (Fang and Wei 1998; Li *et al.* 1981). With recognizing the environmental effects caused by atmospheric carbon dioxide, there has been a surge of renewed interest in the carbon cycling in soil (Behera and Pati 1986; Li *et al.* 1981; Schlesinger 1997). Soil respiration is the loss of carbon (in the form of CO_2) from soils as a result of both microbial activities and root respiration (Sing and Gupa 1997). Soil temperature and water content play an important part in determining soil respiration rates, and soil respiration is regulated by soil temperature and soil water content (Moore and Knowles 1989; Robert and Keith 1985; Upadhyaya *et al.* 1981). Our study focused on the responses of soil respiration rate to soil temperature and soil water content in 3 typical forest ecosystems in Changbai Mountain.

Soil respiration is affected by many factors. Fang (1998) studied the relation between latitudinal change and soil respiration rate in the forest. The respiration rate tended to decrease linearly with latitudinal change. However, in our study the effects of soil temperature on the soil respiration were different in various forest ecosystems. Under different soil water contents the effect of elevated temperature on the soil respiration in broad-leaved/Korean pine forest was significantly different, especially in the middle level of soil water contents. The relationship between soil respiration and temperature can be well demonstrated by Q_{10} of soil respiration. The mean Q_{10} values of soil respiration in broad-leaved/Korean pine forest, dark coniferous forest, and Erman's birch forest were 3.05, 2.72 and 3.67, respectively, which were higher than that (2-2.5) in the grassland by Singh *et al.* Q_{10} value for Mountain soddy forest soil was the highest among 3 different forest systems. This was consistent with the result from Krischbaum (1995). Q_{10} value was higher at low temperatures than that at elevated temperatures. It was observed that elevated temperatures in the Northern Hemisphere had more significant effects on soil respiration than that at low altitude regions (Fang *et al.* 2001). The result is an important predict for the dynamic change in soil carbon pool after global climate change. The values of Q_{10} had the similar changing tendency to the different temperatures at different soil water contents in broad-leaved/Korean pine forest and erman's birch forest. It decreased as the temperature went up and the difference of the change was significant. The value of Q_{10} at elevated soil water content was higher than that at low soil water content. When soil is very dry the soil respiration is restrained (Kucera and Kirlcham 1971). When soil is very wet the soil respiration rates reduce. Soil respiration was affected by temperature or soil water content (De *et al.* 1974; Gupta and Singh 1981; Kucera and Kirlcham 1971). The results of soil respiration in the grassland showed that the maximum of respiration rate occurred in optimal temperature with the largest amount of precipitation (Yang *et al.* 1989), which was similar in erman's birch forest. On the contrary, in broad-leaved/Korean pine forest and dark coniferous forest, the maxima of respiration rates were observed at optimal soil water content and at the highest temperature, which demonstrated that soil respiration was affected by multi-factors (Jenkinson *et al.* 1991; Liu and Fang 1997). The gas permeability in the soil of erman's birch forest is good (Chen *et al.* 1999) and at the same soil water content CO_2 easily release from the forest soil. Our study demonstrated that the soil respiration was reciprocally affected by both temperature and soil water content (Fig. 1, 2) (Fang *et al.* 2001; Moore and Knowles 1989; Wildung *et al.* 1975; Yang 1989). Moreover, since broad-leaved/Korean pine forest, dark coniferous forest and erman's birch forest are located at different altitudes ranged from 600 m to 800 m and the soil temperature difference at the same time is 4-5 °C. Therefore, in the field the soil respiration rate measured in dark coniferous forest is lower than that in broad-leaved/Korean pine forest and it is higher in mountain soddy forest soil than that in dark coniferous forest.

It was suggested that soil CO_2 releasing was dependent on the number of microbes, biomass and its activities in the soil (Chen *et al.* 1999; Jenkinson *et al.* 1991; Moore and Knowles 1989). We found that the soil respiration rates varied greatly in different forest ecosystems.

Our results can provide valuable data in the response of soil respiration to soil temperature and water content in different forest types in Changbai Mountain. The yearly carbon flux releasing from soil respiration in different forest ecosystems can be estimated by combining with the data of yearly soil water content and temperature or finding out the relationship between yearly dynamic precipitation and soil water content. It is important to understand the regional carbon balance in the ecosystem.

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